

ARCHAEOLOGY

Pre-Clovis occupation 14,550 years ago at the Page-Ladson site, Florida, and the peopling of the Americas

Jessi J. Halligan,^{1*†} Michael R. Waters,^{2,3,4*†} Angelina Perrotti,³ Ivy J. Owens,^{5,6} Joshua M. Feinberg,^{7,8} Mark D. Bourne,^{7,8} Brendan Fenerty,⁹ Barbara Winsborough,¹⁰ David Carlson,³ Daniel C. Fisher,¹¹ Thomas W. Stafford Jr.,¹² James S. Dunbar¹³

Stone tools and mastodon bones occur in an undisturbed geological context at the Page-Ladson site, Florida. Seventy-one radiocarbon ages show that ~14,550 calendar years ago (cal yr B.P.), people butchered or scavenged a mastodon next to a pond in a bedrock sinkhole within the Aucilla River. This occupation surface was buried by ~4 m of sediment during the late Pleistocene marine transgression, which also left the site submerged. *Sporormiella* and other proxy evidence from the sediments indicate that hunter-gatherers along the Gulf Coastal Plain coexisted with and utilized megafauna for ~2000 years before these animals became extinct at ~12,600 cal yr B.P. Page-Ladson expands our understanding of the earliest colonizers of the Americas and human-megafauna interaction before extinction.

INTRODUCTION

Genetic studies of modern Native Americans and ancient human skeletons indicate that the initial peopling of the Americas occurred before the appearance of the Clovis complex, dated to ~13,000 calendar years before the present (cal yr B.P.) (1, 2), but this interpretation requires confirmation by empirical archaeological evidence. The archaeological record demonstrating that humans occupied the Americas between ~14,000 and 15,000 cal yr B.P. is still sparse because of a number of factors, most importantly site visibility and recognition. At present, pre-Clovis sites include Paisley Caves, Oregon (3); Schaefer and Hebior, Wisconsin (4); Monte Verde, Chile (5); Debra L. Friedkin, Texas (6); and others (7, 8). Here, we report our investigations at the Page-Ladson site, Florida, where artifacts dating to ~14,550 cal yr B.P. were found in a buried and well-dated stratified context. Page-Ladson is the first pre-Clovis site to be documented in the southeastern portion of North America and demonstrates that the earliest people to enter North America were exploring the Gulf Coastal Plain at the same time other areas of the continent were being populated. Proxy evidence from the sediments at Page-Ladson also indicate that humans coexisted with megafauna in the American Southeast for ~2000 years before the large mammals became extinct at ~12,600 cal yr B.P.

Site setting

The Page-Ladson site lies submerged under 9 m of water within a mid-channel sinkhole along a segment of the Aucilla River, ~11.5 km inland from the Gulf of Mexico (Fig. 1A). This segment of the aquifer-fed river

flows across karstified Oligocene limestone with disconnected surface channels linked by subterranean drainage conduits (9). The Page-Ladson sinkhole, which is ~60 m in diameter, is bounded by bedrock on all sides and is connected to sinkholes upstream and downstream by shallow bedrock channels (section S2.1).

The site was first investigated from 1983 to 1997 (Fig. 1, B and C), and the original investigators reported finding eight stone artifacts associated with butchered mastodon remains from a deposit radiocarbon dated to ~14,400 cal yr B.P. (10). These findings were challenged, and the site was relegated to an ambiguous status (11, 12). We returned to Page-Ladson in 2012–2014 to evaluate the archaeological and geological context of the potentially early archaeological component and to gather proxy evidence to assess the timing of megafaunal extinctions. Our investigations occurred adjacent to and expanded the previous investigations along the western margin of the sinkhole (section S1).

RESULTS

Geological and chronological context

In our excavations, the late Quaternary deposits were ~4-m thick and divided into seven stratigraphic units labeled 1 to 7, from oldest to youngest (13). Unit 1 is an undated sandy marl. Unit 2 is a woody cypress peat dating in excess of ~17,000 cal yr B.P. These two units were not the focus of this research because neither unit contained cultural material (section S2.2).

Our studies concentrated on Units 3 to 7, from which we radiocarbon-dated 71 wood samples deposited contemporaneously with the sediments (Figs. 2 and 3 and sections S2.2 to S2.4). Artifacts older than Clovis were found in Units 3 and 4.

Unit 3 is subdivided into three members, with Units 3a and 3b deposited ~16,000 to 14,700 cal yr B.P. Unit 3c, which dates from ~14,700 to 14,400 cal yr B.P. and where pre-Clovis artifacts were found, consists of sand and fine gravel intermixed with mastodon digesta deposited in and adjacent to a pond at the bottom of the sinkhole (14). Terrestrial diatoms, microscopic evidence of woody roots and earthworm activity, and the occasional mastodon track and discrete dung boluses show that the pond

¹Department of Anthropology, Florida State University, Tallahassee, FL 32306, USA. ²Center for the Study of the First Americans, Texas A&M University, College Station, TX 77843, USA. ³Department of Anthropology, Texas A&M University, College Station, TX 77843, USA. ⁴Department of Geography, Texas A&M University, College Station, TX 77843, USA. ⁵Department of Archaeology, University of Exeter, Exeter EX4 4QE, UK. ⁶The Charles McBurney Laboratory for Geoarchaeology, Division of Archaeology, University of Cambridge, Cambridge CB2 3DZ, UK. ⁷University of Minnesota, Minneapolis, MN 55455, USA. ⁸Institute for Rock Magnetism, Department of Earth Sciences, University of Minnesota, Minneapolis, MN 55455, USA. ⁹Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA. ¹⁰Texas Memorial Museum, University of Texas, Austin, TX 78705, USA. ¹¹Museum of Paleontology and Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI 48109, USA. ¹²Stafford Research Laboratories, Lafayette, CO 80026, USA. ¹³Aucilla Research Institute Inc., 555 North Jefferson Street, Monticello, FL 32344, USA.

*These authors contributed equally to this work.

†Corresponding author. Email: jhalligan@fsu.edu (J.J.H.); mwaters@tamu.edu (M.R.W.)

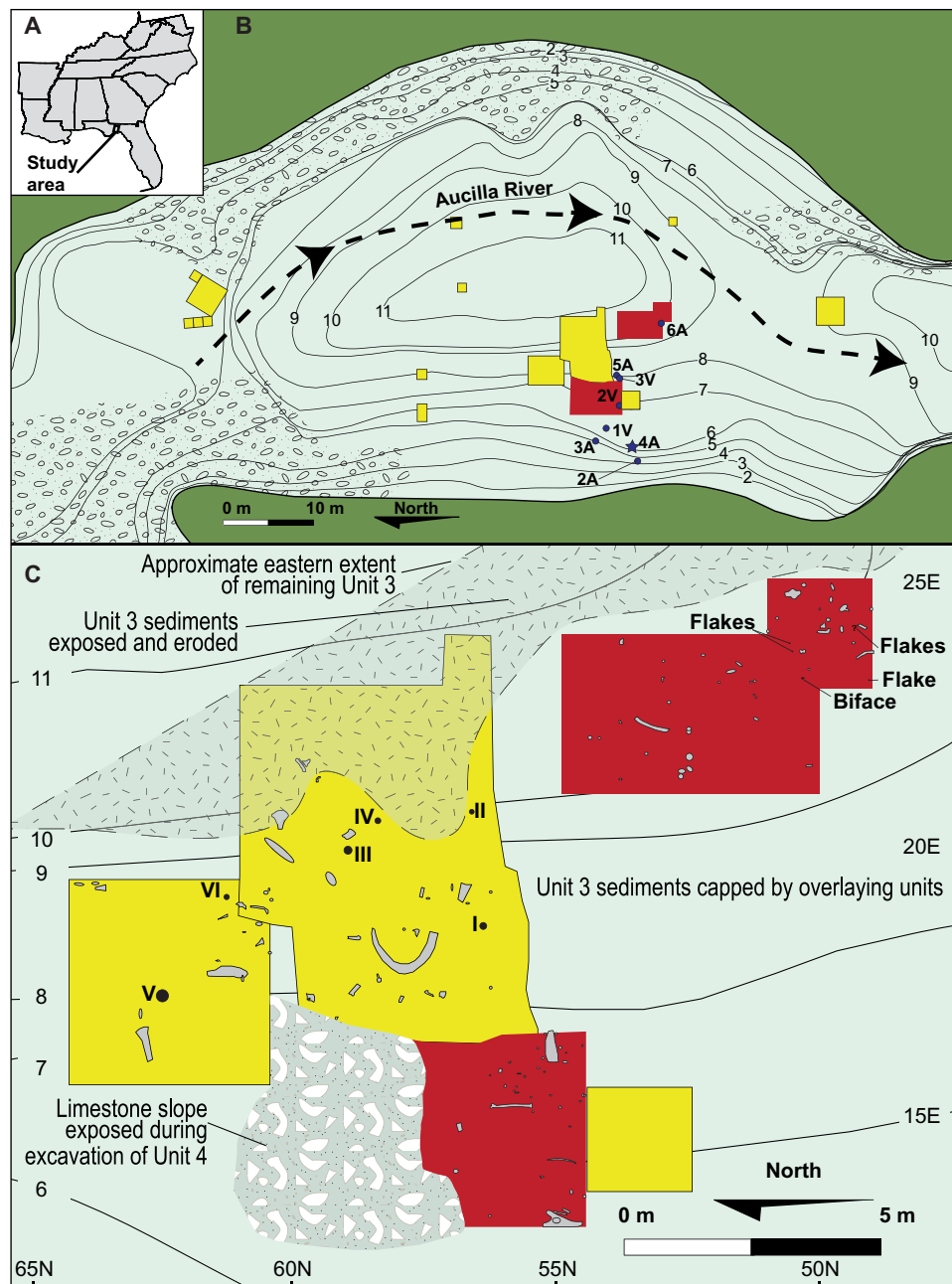


Fig. 1. Page-Ladson site map. (A) Location of Page-Ladson in northwestern Florida. (B) Map of the Page-Ladson underwater excavations, showing the entire sinkhole and previous excavation areas, as well as excavation areas and sediment cores reported in this paper. Core 4A is marked with a blue star. Other cores are marked with blue circles. Previous excavations are marked with yellow. Our excavations are marked with red. Contours are in meters below datum. (C) Detailed map displaying the location of bones (gray), drawn to scale, and artifacts (black) recovered from geological Units 3a to 3c and 4a to 4b.

margin dried for short periods of time and was subaerially exposed, allowing animals and humans to enter the sinkhole (section S2).

Unit 4, composed of fine-grained sediments, is subdivided into three members dating from ~14,400 to 12,600 cal yr B.P. Pre-Clovis artifacts were recovered from Units 4a and 4b. Diatoms and micromorphological studies show that these sediments were deposited in a seasonally fluctuating pond with periodic desiccation along the pond margins. Unit 5, an organic-rich clayey silt with evidence of pedogenic alteration,

dates from ~12,600 to 11,400 cal yr B.P. The absence of freshwater diatoms, extensive pollen degradation, anomalous decrease in the concentration of iron-bearing magnetic minerals, and evidence of human occupation within the sinkhole indicate that this was an arid period (section S2). Units 6 and 7 indicate a return to rapid sedimentation of silt and peat from ~11,400 to at least ~8500 cal yr B.P. Diatoms indicate fully aquatic conditions with only rare evidence of desiccation (section S2.6). The entire late Quaternary sediment package contains

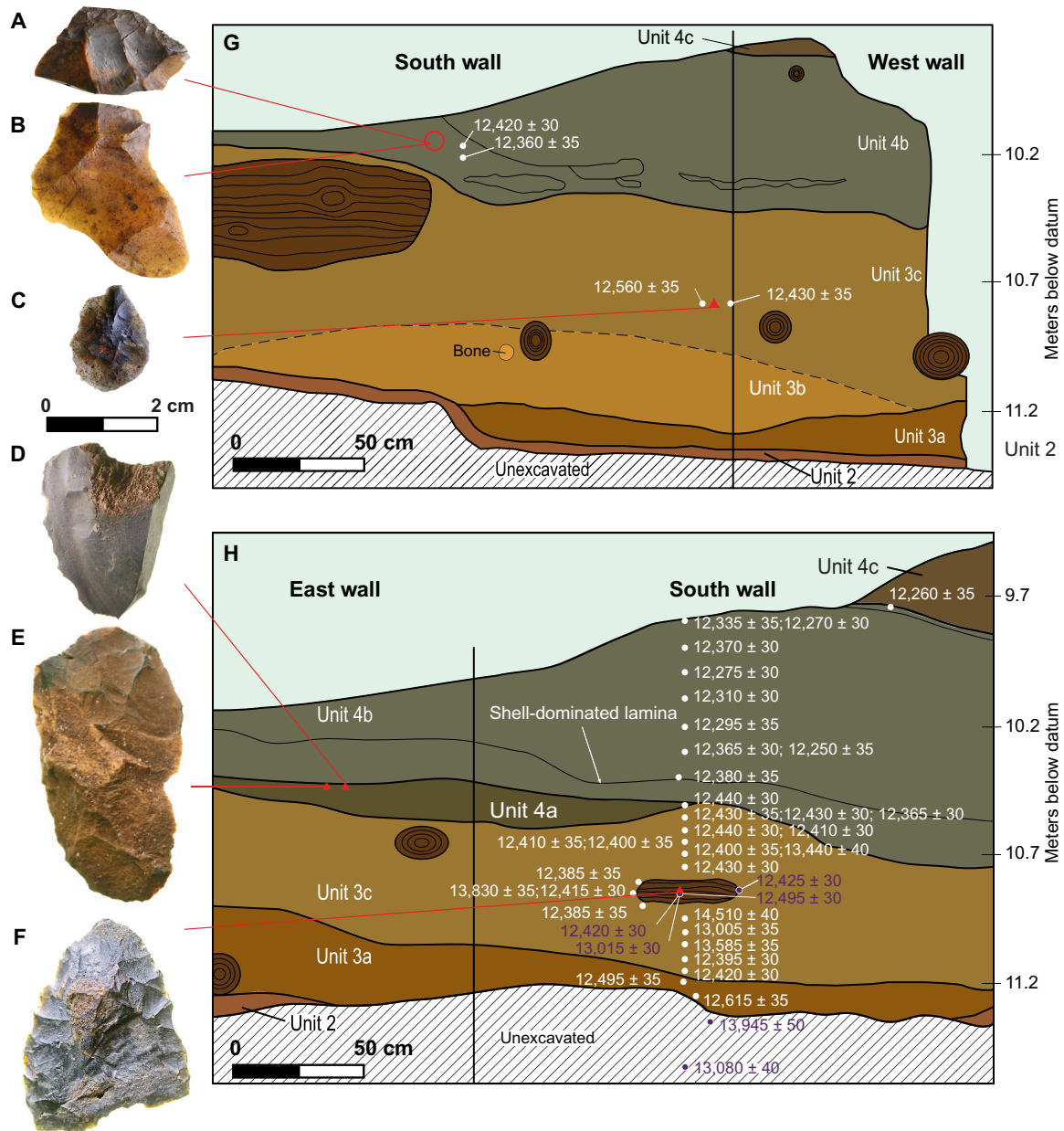


Fig. 2. Stratigraphy of excavation units at the Page-Ladson site displaying pre-Clovis artifacts and radiocarbon ages. (A) Artifact 12209-a. (B) Artifact 12209-b. (C) Artifact 12242-1. (D) Artifact 12068-2. (E) Artifact 12068-1. (F) Artifact 12080-1. (A) to (E) are flakes; (D) shows evidence of use. (F) is a biface. (G) 2014 wall profiles showing stratigraphy, locations of artifact finds, and location of radiocarbon samples. (H) 2013 wall profiles showing stratigraphy, locations of artifact finds, and location of radiocarbon samples. For (G) and (H), white dots represent locations and ages of radiocarbon samples collected from profiles. Purple dots and text represent radiocarbon ages collected from within units, plotted with correct elevation, and northing or easting. Red triangles show locations of artifacts collected from within units, plotted with correct elevation, and northing or easting. Open red circle shows approximate location of artifact found in the screen. Trees in the profile are represented by dark brown. Note that although the biface appears as if it were found in the middle of a tree, the tree only occurs in the south wall profile and does not extend into the excavation unit where the biface was found.

minimal postdepositional disturbance based on magnetic and micro-morphological studies and radiocarbon ages (sections S2.3 to S2.7).

Periods of deposition and nondeposition as well as changing sedimentation rates at Page-Ladson from ~14,900 to 8500 cal yr B.P. appear to correlate with sea level fluctuations when ocean levels rose from 100 to 20 m below modern sea level (15, 16), even though the site was ~250

to 175 km inland during this time. Unit 3c was deposited during a short period of unchanged sea level. Rapid sea level rise from ~14,500 to 14,000 cal yr B.P., which is the onset of the Bølling-Allerød warm period corresponding to meltwater pulse 1A, is contemporaneous with the rapid deposition of Units 4a and 4b and the highest rates of sedimentation in the sinkhole. From ~14,000 to 12,500 cal yr B.P., sea level rose at a steady

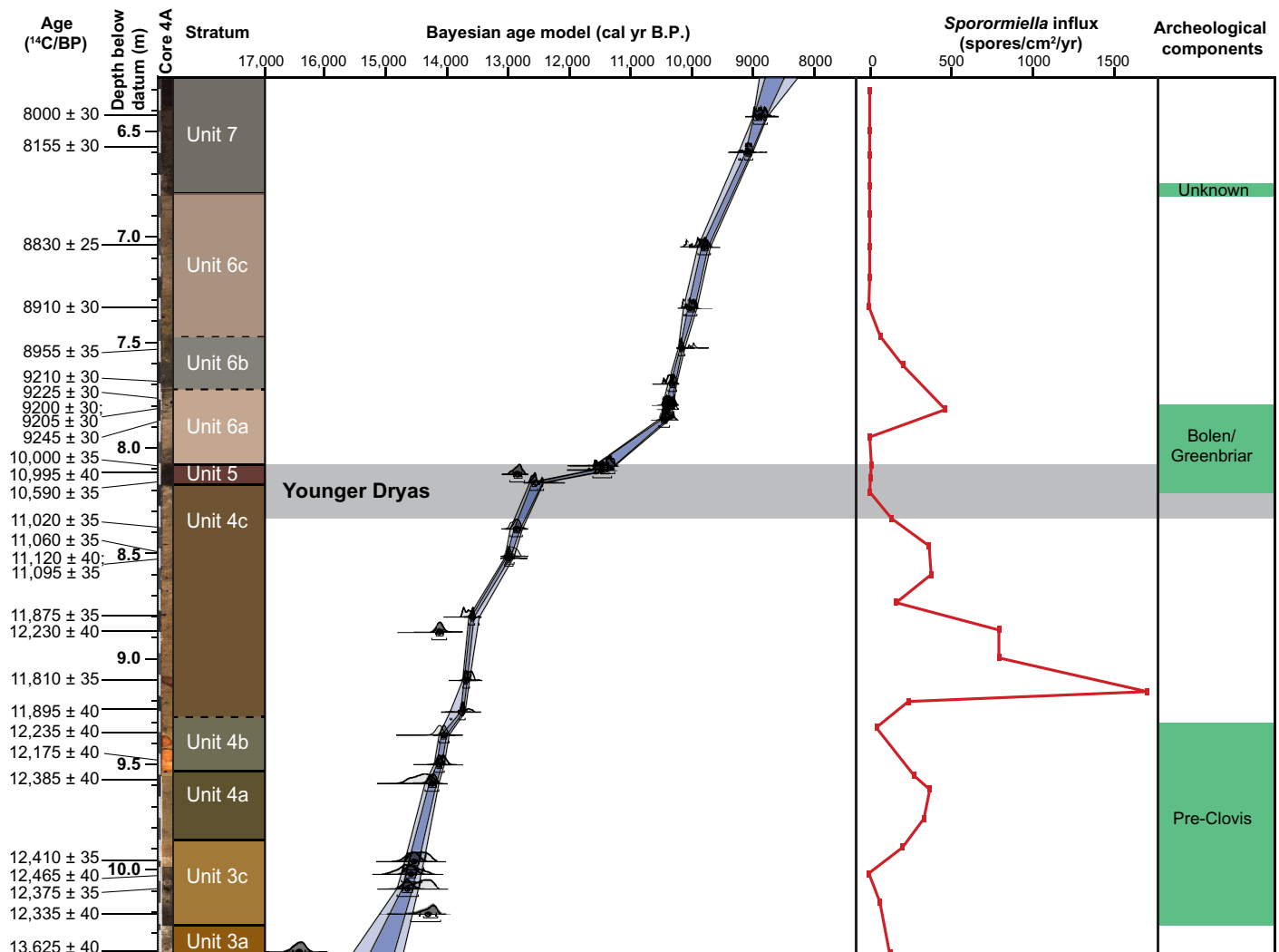


Fig. 3. Core 4A from Page-Ladson. From left to right: Uncalibrated radiocarbon ages and locations; depths below datum; images of core 4A to scale; stratum designations as discussed in text; Bayesian age model of radiocarbon ages from OxCal version 4.2.4 (30–32); *Sporormiella* influx curve calculated from *Sporormiella* concentrations, age model, and sedimentation rates (Supplementary Materials); and archaeological components discovered at the Page-Ladson site plotted by geological association. Younger Dryas stadal (~12,850 to 11,700 cal yr B.P.) is indicated using the age model to determine boundaries.

rate, paralleling the rapid deposition of Unit 4c. A pause in sea level rise from ~12,500 to 11,500 cal yr B.P. corresponds approximately to the Younger Dryas stadal (~12,850 to 11,700 cal yr B.P.) (17, 18) and correlates to the period of minimal deposition, subaerial exposure, and pedogenesis documented by Unit 5. Deposition of Units 6 and 7 took place during a period of rapid sea level rise from ~11,400 to 8200 cal yr B.P. The correlation between sea level rise and deposition at Page-Ladson suggests a hydrologic connection between the site and the ocean through the karstic system (19, 20), with the aquifer response to sea level dictating the tempo of deposition in the sinkhole. Our magnetic studies (section S2.5) suggest that all sediments in the sinkhole are derived from the same source, most likely from the weathered sediments on the margins of the sinkhole. The near absence of charcoal in Unit 3 versus its abundance in all overlying units indicates an increase in regional fires starting from ~14,400 cal yr B.P., resulting in increased sediment yields to the sink (21).

Archaeology and extinctions

We recovered six unequivocal stone artifacts, all made of local coastal plain chert, within Units 3 and 4 (Fig. 2 and section S3). From Unit 3c, we recovered two artifacts: a biface (Fig. 2F) and a flake (Fig. 2C). The biface, a reworked knife fragment, was recovered in situ during excavation. Seven radiocarbon samples collected immediately adjacent to the biface date to ~14,550 cal yr B.P. The biface is overlain by 1.1 m of Unit 3 and 4 sediments. To confirm the age of the biface and to test that this artifact was in an undisturbed context, a vertical series of 24 radiocarbon samples was obtained from 1.1 m above ($n = 15$) to 0.6 m below ($n = 9$) the biface (Fig. 2H and sections S2.3 to S2.4). This sequence of nearly identical radiocarbon ages indicates that this artifact was lying in undisturbed sediments. Further, the excavation area from where the biface was discovered is covered and sealed by a continuous shell-dominated marker bed in Unit 4 dated ~14,400 cal yr B.P. One meter horizontally from the biface, a flake was recovered from Unit 3c. It was overlain by

1.1 m of undisturbed sediment, and two radiocarbon ages on wood adjacent to this flake also date to ~14,550 cal yr B.P. Two additional flakes were recovered from Unit 4a, about 40 cm above and 50 cm east of the biface, and two more flakes were recovered from Unit 4b (Fig. 2, A, B, D, and E). Radiocarbon ages obtained on samples adjacent to the flakes in Unit 4b indicate that these artifacts date to ~14,200 to 14,550 cal yr B.P. (Fig. 2G). The context in which we found the artifacts correlates with the previous finding of pre-Clovis artifacts at the site (10). The small artifact assemblage recovered from the pre-Clovis occupation at Page-Ladson is consistent with the small number of artifacts found at other pre-Clovis (4, 22) and some Clovis (12, 23) butchering and scavenging sites.

These artifacts occur in deposits that contain extinct mammal remains (mastodon, camelid, and bison) (section S4). During the previous excavations in 1993, a mastodon tusk was recovered from Unit 3c, with multiple, parallel, deep, linear grooves running perpendicular to the long axis of the tusk (24). Because the grooves occur on the alveolar portion of the tusk surface, these marks were originally interpreted as having been made by stone tools during removal of the tusk from the skull. Our reexamination of these marks confirms that they were indeed made by humans, and we agree that they were likely produced during the extraction of the tusk from the alveolus (section S4.2). Although we found no faunal remains with evidence of butchering, two potentially butchered megafaunal bones were previously reported (10). Further, the previous excavators (25) reported finding domesticated dog (*Canis familiaris*) in Unit 3, but this identification has not been confirmed.

The timing of the extinction of megafauna in the American Southeast is unknown. It has been suggested to be contemporaneous with (26), or even later than, elsewhere in North America (27). Proxy evidence from the Page-Ladson sediments allows us to evaluate regional fluctuations in the abundance of megaherbivores, specifically proboscideans, and to estimate the timing of their extinction. We examined Units 3 to 7 for *Sporormiella*, a dung fungus unique to herbivore dung, which has been successfully used as a proxy to establish the time of late Pleistocene megamammal extinctions at other sites in North America (28). At Page-Ladson, we found high concentrations of *Sporormiella* in late Pleistocene Units 3 and 4 (Fig. 3 and section S5). Peak spore concentrations occur around ~13,700 cal yr B.P., potentially indicating the timing of peak megafaunal abundance in the vicinity of the sinkhole. A rapid decline in spore concentrations followed, with *Sporormiella* absent at the top of Unit 4 by ~12,600 cal yr B.P., after the onset of the Younger Dryas stadial. The concurrent decline in spore concentrations and the disappearance of mastodon digesta suggest that mastodon and other megafauna populations decreased in abundance and disappeared from the region by ~12,600 cal yr B.P. Spores are absent from Unit 5 and the lower portion of Unit 6 from ~12,600 to 10,400 cal yr B.P. An anomalous spike in *Sporormiella* concentrations occurs in the middle of Unit 6 from ~10,400 to 10,100 cal yr B.P., after which concentrations decline to zero. The disappearance of *Sporormiella* at ~12,600 cal yr B.P. indicates that the extinction of the megaherbivores in Florida and the American Southeast was synchronous with extinctions elsewhere in North America (22, 26, 28). The spike in *Sporormiella* during the early Holocene may represent a brief expansion of bison into Florida during the Early Archaic Bolen cultural period (section S5).

CONCLUSIONS

The Page-Ladson site contributes to our emerging understanding of the first people to explore and colonize the Americas. At Page-Ladson,

hunter-gatherers, possibly accompanied by dogs, butchered or scavenged a mastodon carcass at the sinkhole's edge next to a small pond at ~14,550 cal yr B.P. These people had successfully adapted to their environment; they knew where to find freshwater, game, plants, raw materials for making tools, and other critical resources for survival. This occupation was during the ~14,000 to 15,000 cal yr B.P. period when there is clear evidence that humans were exploring and settling the Americas. Page-Ladson is located ~8500 km from Monte Verde, ~3500 km from Paisley Caves, and ~1500 km from the Schaefer, Hebior, and Friedkin sites, where other successful groups of hunter-gatherers were adapting to those environments. As at other places, the people at Page-Ladson coexisted with and utilized megafauna for ~2000 years before these animals became extinct at ~12,600 cal yr B.P.; however, the role humans played in this extinction process is unknown.

The record of human habitation of the Americas between ~14,000 and 15,000 cal yr B.P. is sparse but real. The rarity of these early sites along the Gulf Coastal Plain of North America is largely due to two factors: sediment preservation, and burial and submergence during the late Pleistocene transgression. Page-Ladson shows that much of the earliest record of human habitation of the American Southeast lies submerged and buried in unique depositional settings like those found along the Aucilla River. This record can only be accessed through underwater investigation, which, if undertaken with intensity and focus, should reveal a rich and abundant pre-Clovis record for the American Southeast.

MATERIALS AND METHODS

Underwater excavation was conducted by archaeologists who were also trained SCUBA (self-contained underwater breathing apparatus) divers using trowels and a water dredge (section S1). Excavations occurred in 5- or 10-cm levels, with all sediments sieved on the water surface through nested 1/4" and 1/16" mesh. Locations of stratigraphic boundaries, artifacts, and bones larger than 2 cm were recorded during excavation. Spatial locations of all artifacts and samples were obtained from underwater laser control points set by Total station on land. Radiocarbon samples were collected in situ during excavation, from freshly cleaned profiles and from cores. ¹⁴C measurements were determined at the W. M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory. Calibrated radiocarbon ages (cal yr B.P.) were given as 1 – σ probability calendar year ages using Calib 7.0.2 (29, 30), and Bayesian analysis was done following that of Ramsey (31, 32) (sections S2.3 to S2.4). Cores were collected using a vibrocorer or a Livingstone device (section S1.4). All cores were recorded, analyzed, and subsampled at LacCore at the University of Minnesota. Paleoenvironmental analyses are discussed completely in the Supplementary Materials.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/2/5/e1600375/DC1>

fig. S1. Overview of the Page-Ladson site.

fig. S2. Location of underwater excavations and recovered sediment cores at the Page-Ladson site.

fig. S3. Digital elevation model (DEM) map of the Page-Ladson site derived from satellite

(LiDAR) imagery displaying boundaries of terrestrial testing, specific locations of diagnostic

lithic artifacts, and densities of ceramic and lithic materials recovered from terrestrial testing.

fig. S4. Generalized schematic of excavation methodology, facing south (downstream).

fig. S5. Biface in situ.

fig. S6. Biface close up, showing biface on digesta.
 fig. S7. Micromorphology sample locations, facing south (downstream).
 fig. S8. DEM of the Page-Ladson area derived from bare earth LiDAR imagery.
 fig. S9. Generalized cross section of preserved sediments on the western portion of the Page-Ladson site, facing south.
 fig. S10. Close-up composite of core 4A displaying unit designations as described below.
 fig. S11. Bayesian age model for core PLAD-AUC14-4A.
 fig. S12. Bayesian age model for excavation unit 50N/23E.
 fig. S13. Summary of magnetic susceptibility and gamma density for PLAD-AUC14 cores.
 fig. S14. Example hysteresis loops from PLAD-AUC14-4A.
 fig. S15. Composition of titanomagnetite from hysteresis parameters for samples from 3A and 4A.
 fig. S16. Day plot of hysteresis and backfield parameters for samples from 3A and 4A.
 fig. S17. Magnetic susceptibility for PLAD-AUC14-4A showing high susceptibility in Units 4 and 6.
 fig. S18. Correlation of magnetic susceptibility with sea level in the Gulf of Mexico and globally averaged ice-volume equivalent sea level change.
 fig. S19. Diatom sample locations in PLAD-AUC14-4A.
 fig. S20. Diatom abundance in core PLAD-AUC14-4A.
 fig. S21. The locations of the block micromorphology samples within the 2013 south wall profile, the locations of the microstrata within the block samples, and representative photomicrographs of the microstrata.
 fig. S22. Left is slide 12257 in oblique incident light (OIL), 43 mm across.
 fig. S23. Left is slide 12255 in OIL, 43 mm across.
 fig. S24. From Unit 4b in PPL, the root residue in a channel (left, slide 12257) and the probable earthworm granule (right, slide 12254).
 fig. S25. Flakes recovered from lower strata at Page-Ladson.
 fig. S26. Biface (AM 12080-1) from Unit 3c.
 fig. S27. Photo of marks on Page-Ladson mastodon tusk (UF 150701) taken shortly after excavation, before formation of desiccation fractures of the cementum layer.
 fig. S28. Photo of marks on Page-Ladson mastodon tusk (UF 150701) taken after formation of desiccation fractures of the cementum layer.
 fig. S29. Comparison of early photos of marks taken before and after formation of a desiccation fracture (figs. S27 and S28).
 fig. S30. Underwater photo of Page-Ladson mastodon tusk in situ.
 fig. S31. Composite photomicrograph of new cast made from Webb's patch mold (24).
 fig. S32. High-resolution photo (low-angle lighting from upper left) of a cast replicating part of the lateral flank of the dorsal half of the proximal tusk segment of UF 150701.
 fig. S33. Lateral aspect of polyurethane mold (and fiberglass mother mold) of the complete left alveolar cavity in the skull of the Hyde Park mastodon (33), rendered from a three-dimensional model.
 fig. S34. Location of *Sporormiella* samples collected from PLAD-AUC14-4A.
 fig. S35. Images of fossil *Sporormiella* from PLAD-AUC14-4A.
 fig. S36. *Sporormiella* influx by depth for core PLAD-AUC14-4A.
 fig. S37. *Sporormiella* influx by cal yr B.P. for core PLAD-AUC14-4A.
 table S1. Present (2015) unit designations related to nomenclature from Kendrick (13).
 table S2. Radiocarbon ages from core 4A.
 table S3. Radiocarbon ages from 2013 excavation units.
 table S4. Radiocarbon ages from 2014 excavation units.
 table S5. Radiocarbon ages from previous excavations (34) used to calculate Unit 5/6a boundary.
 table S6. Modeled ages of each stratum according to PLAD-AUC14-4A showing age spans of each stratum and sedimentation rate for each stratum.
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 table S11. Macrofaunal remains recovered from Units 4b to 3a during 2012–2014 excavations.
 table S12. *Sporormiella* samples from the Page-Ladson site.
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